Near Detector Studies

NOνA Collaboration Meeting

May 15, 2004

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Appearance Probability Measurements

$$N_{far} = \phi_{\nu_\mu} \sigma_{\nu_x} P(\nu_\mu \to \nu_x) \varepsilon_x M_{far} + B_{far}$$

φ=flux, σ= cross section ε=efficiency M=mass

$$P(\nu_\mu \to \nu_x) = \frac{N_{far} - B_{far}}{\phi_{\nu_\mu} \sigma_{\nu_x} \varepsilon_x M_{far}}$$

B_{far}= Backgrounds at far detector, from any flux

$$B_{far} = \sum_{i=\mu,e} \phi_{\nu_i} (P) \sigma_{\nu_i} \varepsilon_{ix} M_{far}$$

Cross Sections matter for Signal and Backgrounds, and indirectly for efficiencies!

Probabilities, continued

$$\left(\frac{\delta P}{P}\right)^2 = \frac{(N_{far} + (\delta B_{far})^2)}{(\phi_{\nu_\mu}\sigma_{\nu_x}\varepsilon_x M_{far})^2} + \frac{N_{far} - B_{far}}{(\phi_{\nu_\mu}\sigma_{\nu_x}\varepsilon_x)^2}[\delta(\phi_{\nu_\mu}\sigma_{\nu_x}\varepsilon_x)]^2$$

$$\left(\frac{\delta P}{P}\right)^2 = \frac{(N_{far} + (\delta B_{far})^2)}{(\phi_{\nu_\mu}\sigma_{\nu_x}\varepsilon_x M_{far})^2} + (N_{far} - B_{far})\left(\left[\frac{\delta\phi_{\nu_\mu}}{\phi_{\nu_\mu}}\right]^2 + \left(\frac{\delta\sigma_{\nu_x}}{\sigma_{\nu_x}}\right)^2 + \left(\frac{\delta\varepsilon_{\nu_x}}{\varepsilon_{\nu_x}}\right)^2\right)$$

2 Regimes:

$$N_{far} >> B_{far}$$

$$N_{far} \approx B_{far}$$

Problem:

Don't always know *a priori* which regime you are in

---depends on Δm^2,

---depends on $\sin^2 2\theta_{13}$

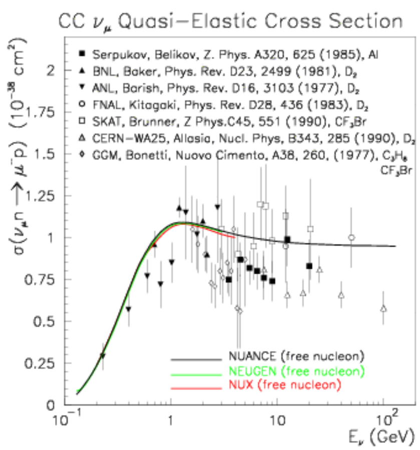
NOνA Event Statistics and Systematics

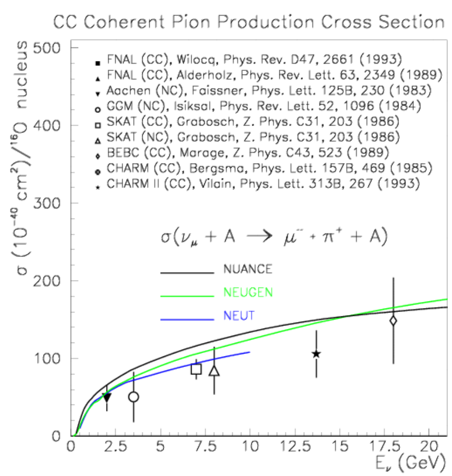
Process	**Statistics**	QE	RES	COH	DIS
$\delta\sigma/\sigma$		20%	40%	100%	20%
Signal ν_e	**175 at $\sin^2 2\theta_{13}$=0.1**	55%	35%	n/i	10%
NC	**15.4**	0	50%	20%	30%
ν_μCC	**3.6**	0	65%	n/i	35%
Beam ν_e	**19.1**	50%	40%	n/i	10%

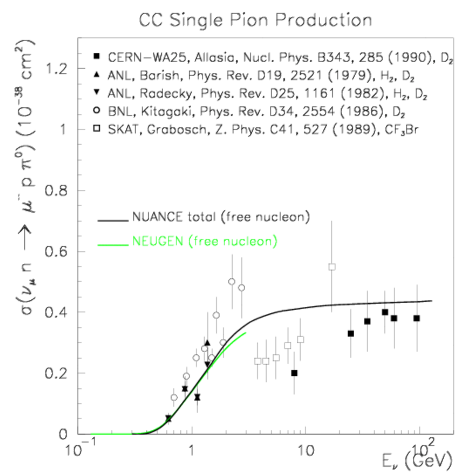
For large $\sin^2 2\theta_{13}$, statistical=8%
For small $\sin^2 2\theta_{13}$, statistical=16%

Assume 50kton,
5 years at 4×10^{20} POT,
$\Delta m^2=2.5\times10^{-3}\text{eV}^2$

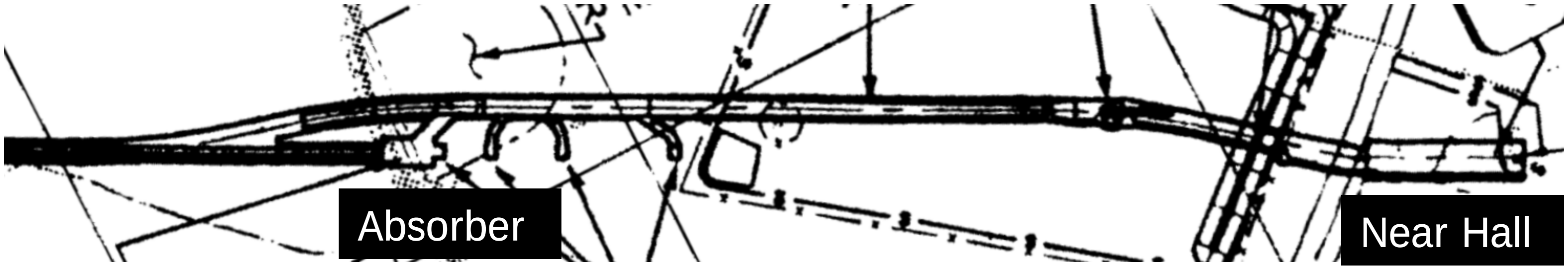
From G.Zeller, NuFact03

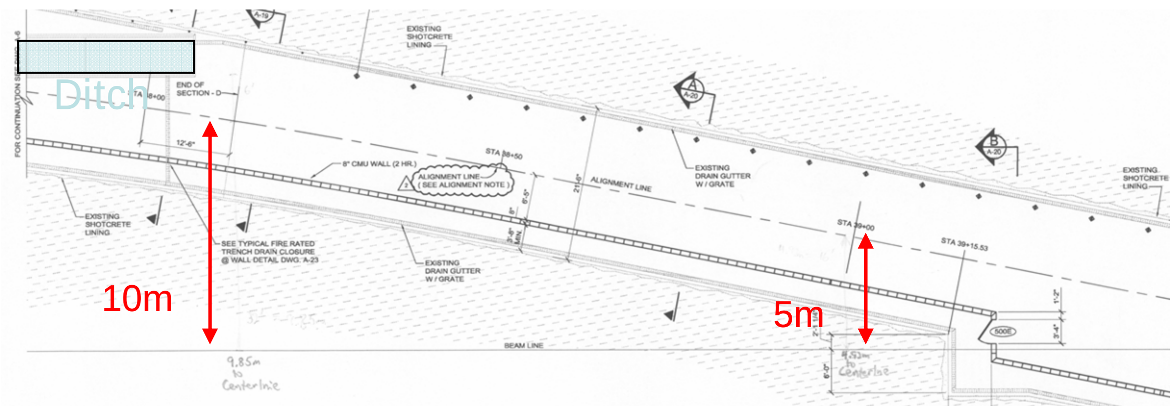


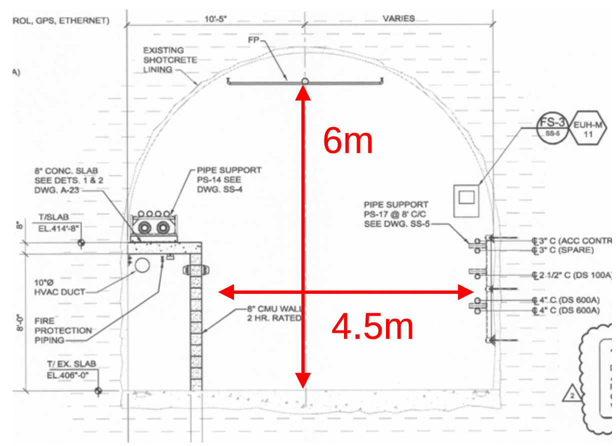




Where can a NOvA Near Detector Go?







- NOνA Near Detector:3.7m wide by 4.9m high,10m long, 22H, 22V planes, 120 tons
- 1m veto, 3m target, 6m “calorimeter”, contains <1.5GeV muons

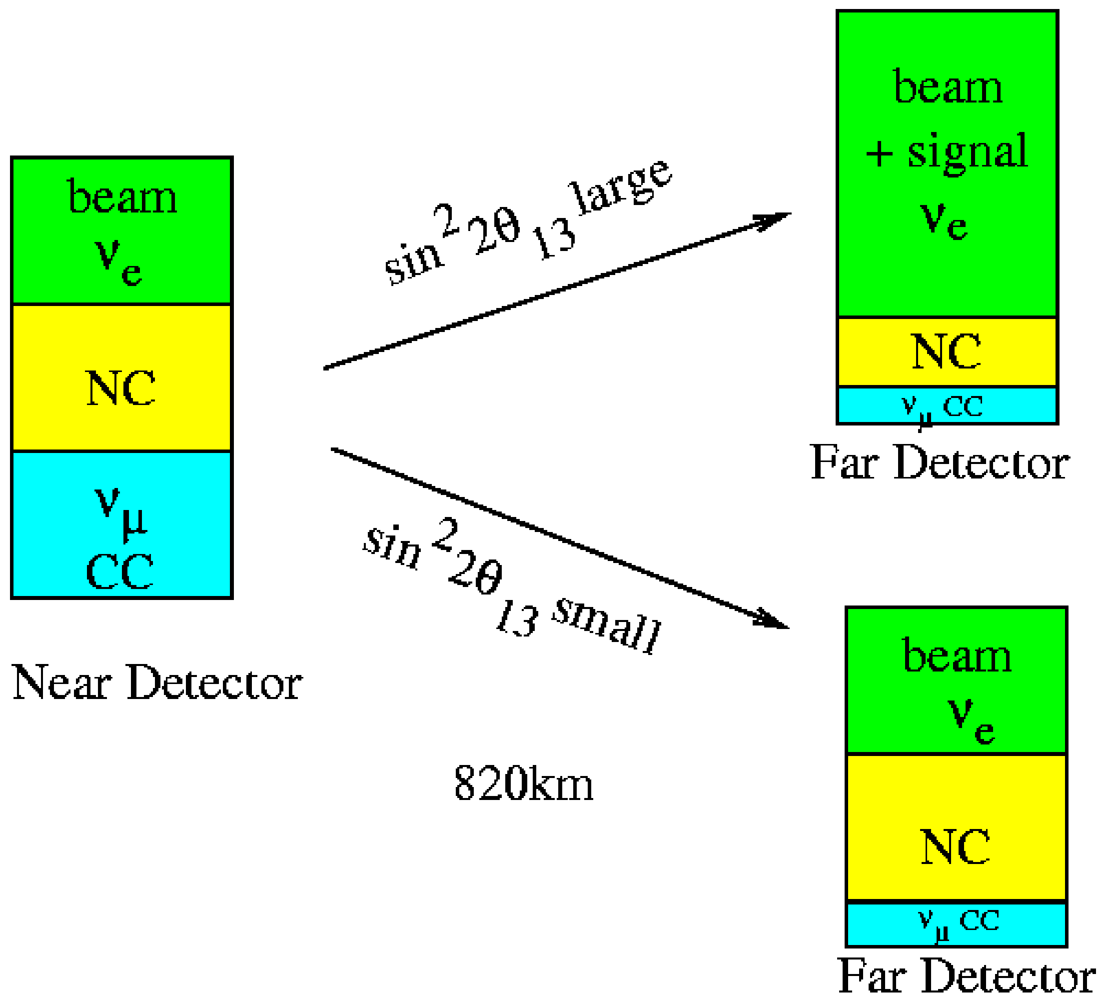
Why measuring $\nu_\mu \rightarrow \nu_e$ with a ND isn't trivial…

Usual statement:

Near Detector sees line source of neutrinos, far detector sees point source:

Peak is narrower at FD
High Energy tail is lower at FD

But large ν_μ disappearance changes fluxes much more than this!



Near Detector Strategy

$$B_{far} = \sum_{i=\mu,e} \phi_{\nu_i\ far}(P)\sigma_{\nu_i}\varepsilon_{ix}M_{far}$$

Backgrounds come from several sources

$$N_{near} = \sum_{i=\mu,e} \phi_{\nu_i\ near}\sigma_{\nu_i}\varepsilon_{ix}M_{near}$$

Build near detector with same ε

$$B_{far} = N_{near}\frac{\sum_{i=\mu,e} \phi_{\nu_i\ far}(P)\sigma_{\nu_i}\varepsilon_{ix}M_{far}}{\sum_{i=\mu,e} \phi_{\nu_i\ near}\sigma_{\nu_i}\varepsilon_{ix}M_{near}}$$

Simulations better at predicting ratios absolute levels

$$B_{far} = \sum_{i=\mu,e} N_{near,i}\frac{\phi_{\nu_i\ far}}{\phi_{\nu_i\ near}}\frac{\sigma_{\nu_i}}{\sigma_{\nu_i}}\frac{\varepsilon_{ix}}{\varepsilon_{ix}}\frac{M_{far}}{M_{near}}$$

Near Detector Strategy (cont'd)

$$B_{far} = \sum_{i=\mu,e} \int dE_\nu N_{near,i} \left(\frac{\phi_{\nu_i\ far}(E_\nu)}{\phi_{\nu_i\ near}(E_\nu)} \right) \left(\frac{\sigma_{\nu_i}(E_\nu)}{\sigma_{\nu_i}(E_\nu)} \right) \left(\frac{\varepsilon_{ix}(E_\nu)}{\varepsilon_{ix}(E_\nu)} \right) \frac{M_{far}}{M_{near}}$$

- But ratios don't cancel everything
- Underlying problem: fluxes are different
  - Near detector: line source, far detector: point source
  - But even if that is solved, still ν_μCC oscillations
- All of these terms are functions of energy
  - Uncertainties in energy dependence of cross sections translate into far detector uncertainties…

Systematics Evaluation—Background Limited Case

$$B_{far} = \sum_{i=\mu,e} N_{near,i} \frac{\phi_{\nu_i\,far}}{\phi_{\nu_i\,near}} \frac{\sigma_{\nu_i}}{\sigma_{\nu_i}} \frac{\varepsilon_{ix}}{\varepsilon_{ix}} \frac{M_{far}}{M_{near}}$$

$$B_{far} = N_{near,i} \frac{\sum_{i=\mu,e}(\phi_{\nu_i\,far}(P)\sigma_{\nu_i}\varepsilon_{ix})}{\sum_{i=\mu,e}(\phi_{\nu_i\,near}\sigma_{\nu_i}\varepsilon_{ix})} \frac{M_{far}}{M_{near}}$$

$$B_{far} = N_{near,i} * R$$

How much does R change by when you change cross Sections by their errors—now and after MINERνA

Systematics Evaluation: What if Θ_{13} is large?

Model: will have a prediction for events in Far detector, which will be a function of $\sin^2 2\Theta_{13}$

$$N_{far} = B_{far} + S_{far}$$

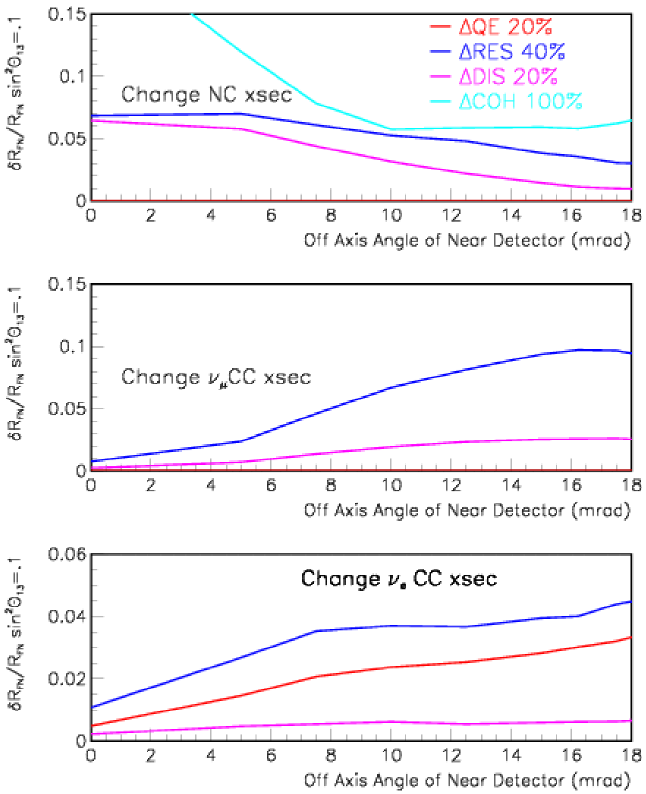
$$N_{far} = N_{near} * R'$$

$$R' = \frac{\sum_{i=\mu,ebeam,eSIGNAL} (\phi_{\nu_i\, far}(P) \sigma_{\nu_i} \varepsilon_{ix})}{\sum_{i=\mu,ebeam} (\phi_{\nu_i\, near} \sigma_{\nu_i} \varepsilon_{ix})} \frac{M_{far}}{M_{near}}$$

R' now depends on background and what Θ_{13} is

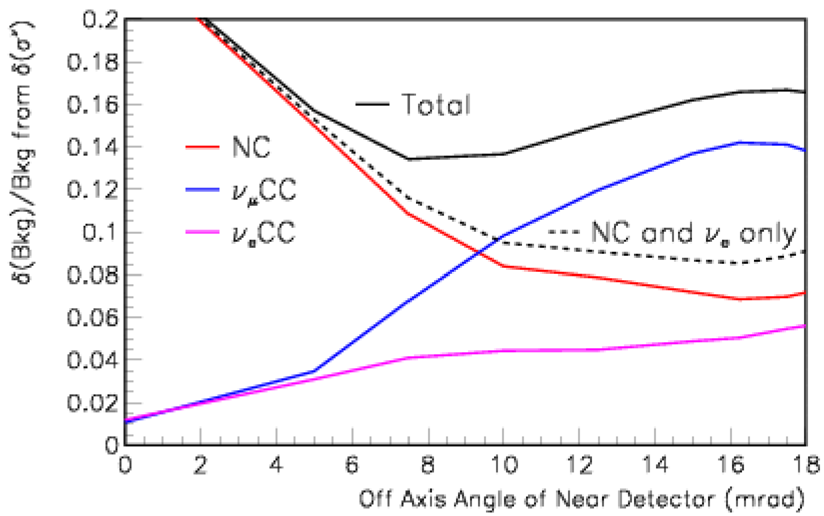
NOνA Systematics now, if Θ_{13} is large

Assume Energy Dependence known….
vary σ levels



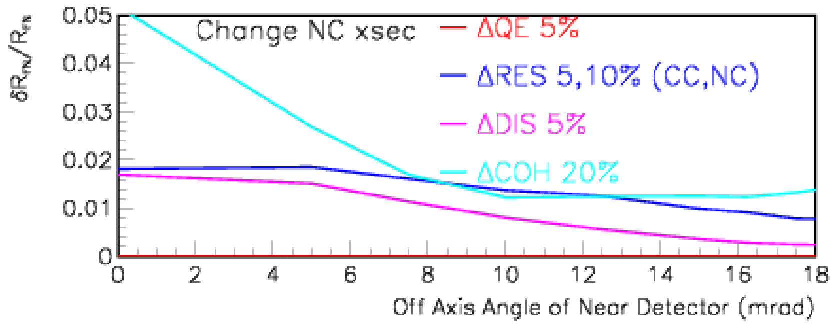
Regardless of NOνA Near Detector Location, large errors in extrapolation To far detector….

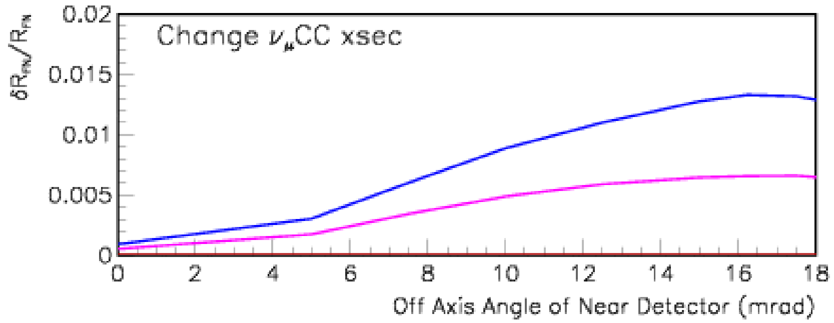
With identical near detector, cross section errors very important, since near & far detector populations are very different

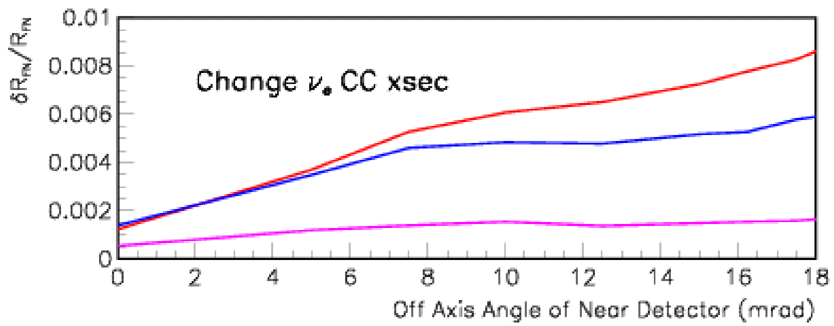


Statistical error, phase 1:
about 8%

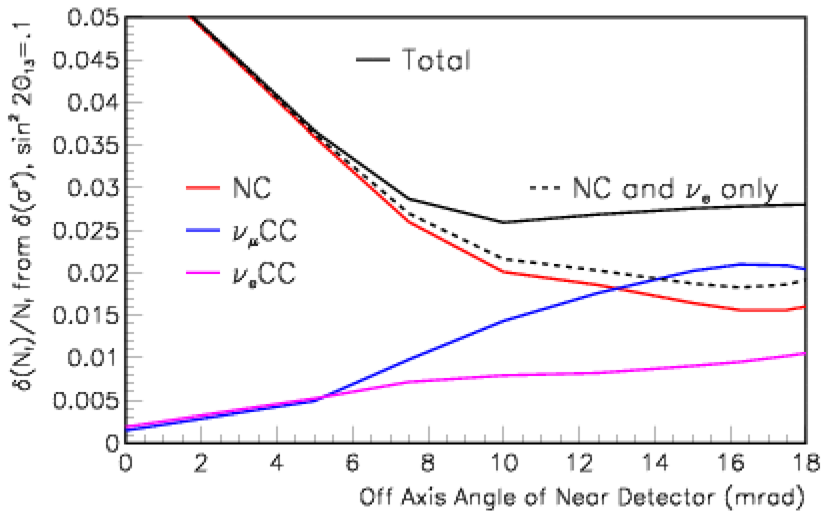
NOνA Systematics for Large Θ_{13}
CC cross sections measured at 5% level





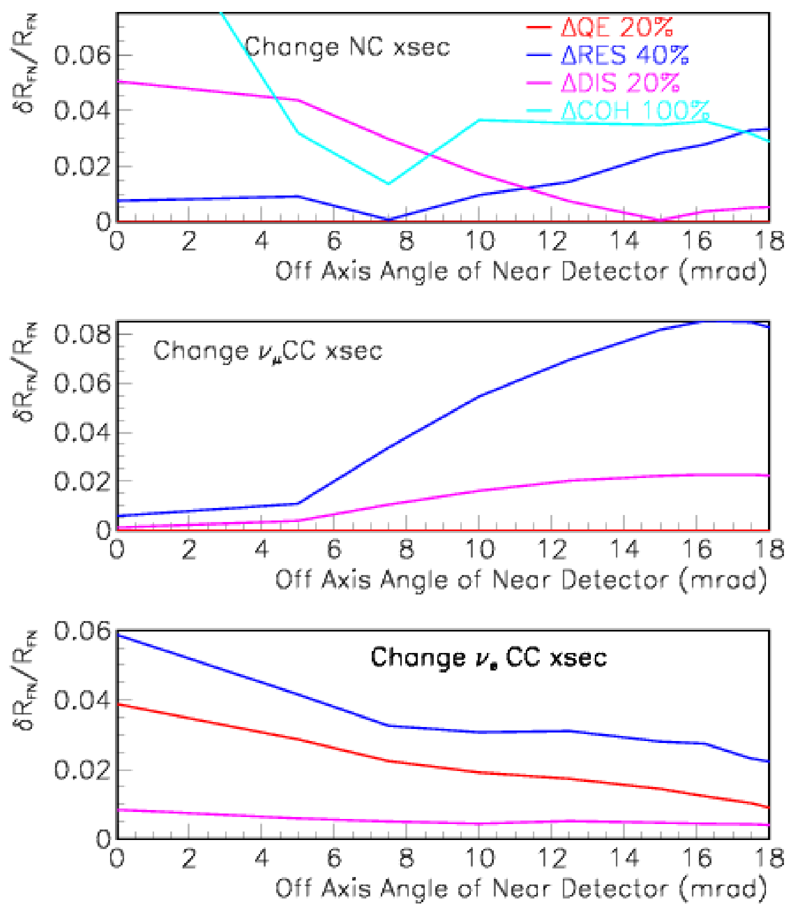


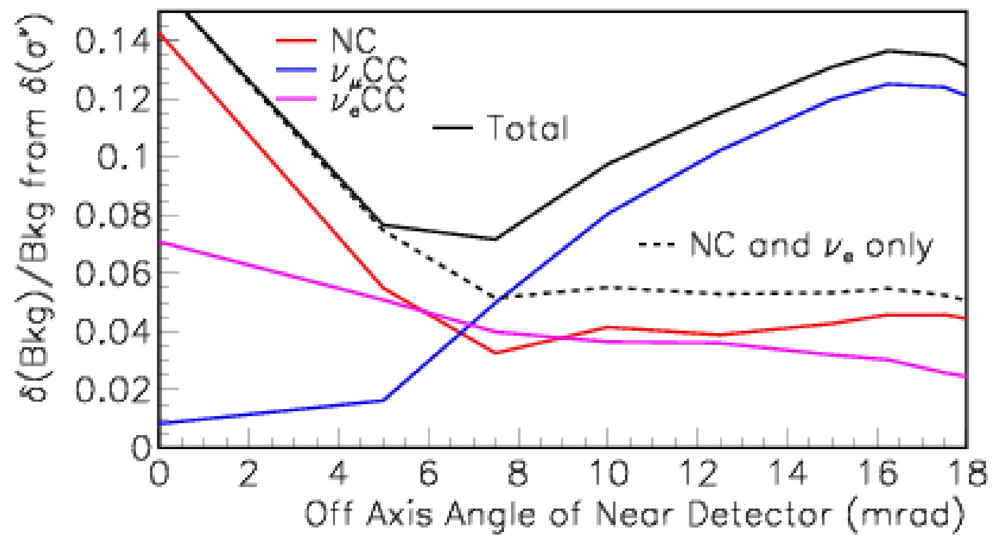
Cross section uncertainties small
Now compared to statistics, and are
At the expected level of the flux
uncertainties



Statistical error, phase 1:
about 8%

NOvA Systematics now, for small Θ_{13}

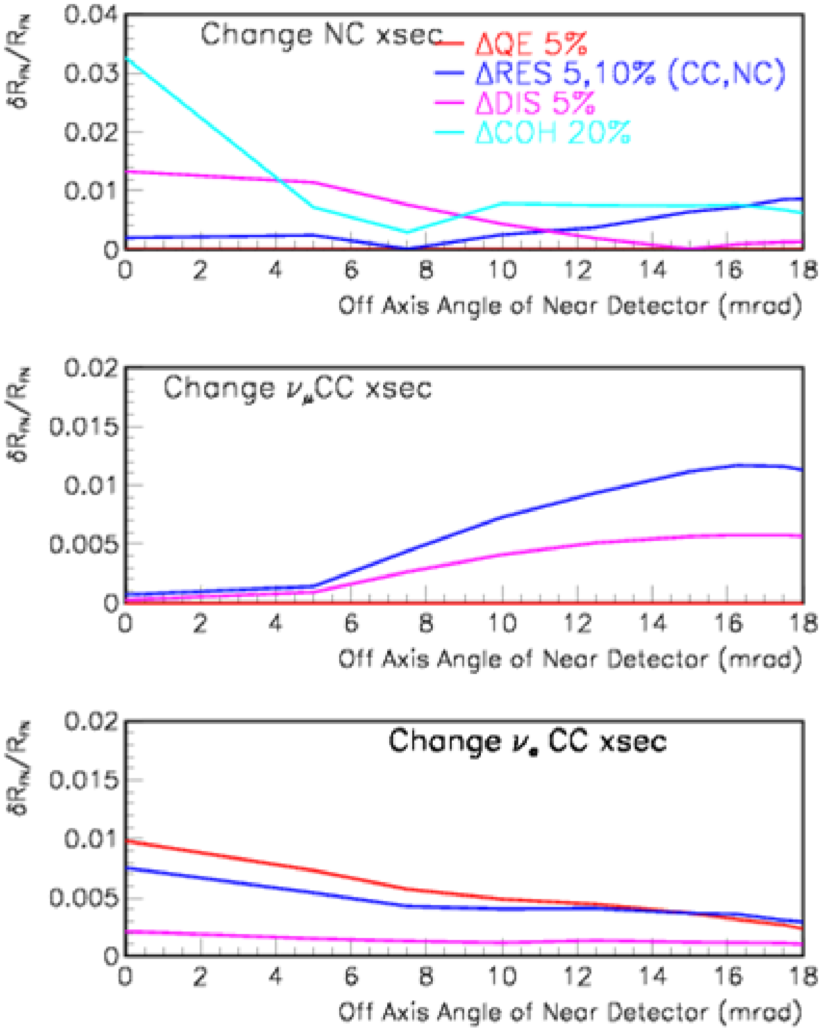


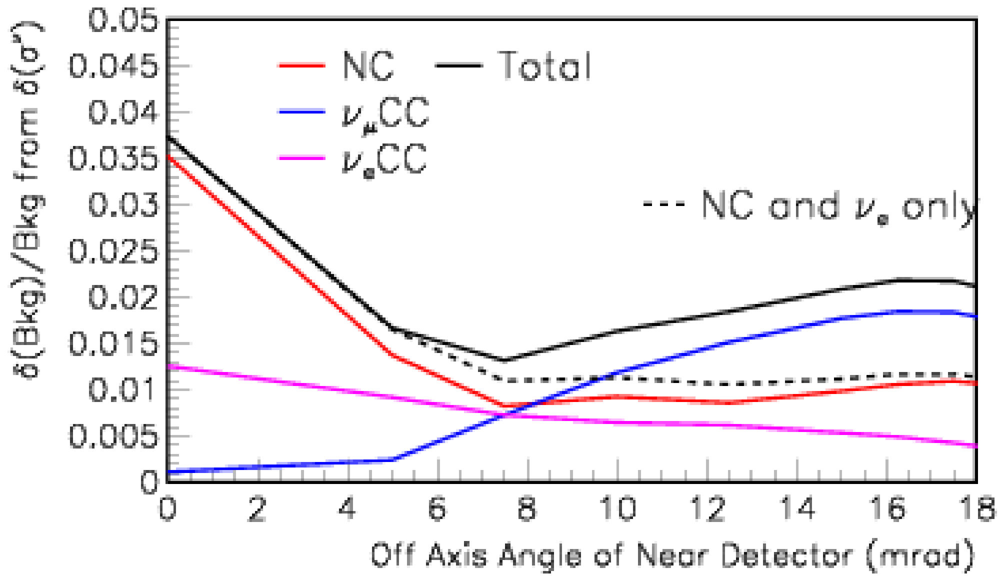


Statistical error, phase I: 15%

Moral of Story: Need Near Detector AND cross section measurements!

NOνA Systematics for small Θ_{13}
NC cross sections measured at 10-20% level

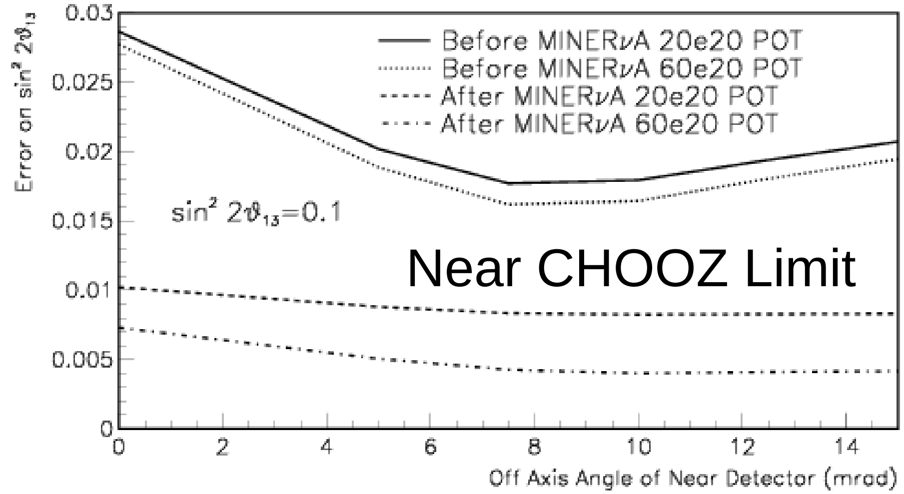


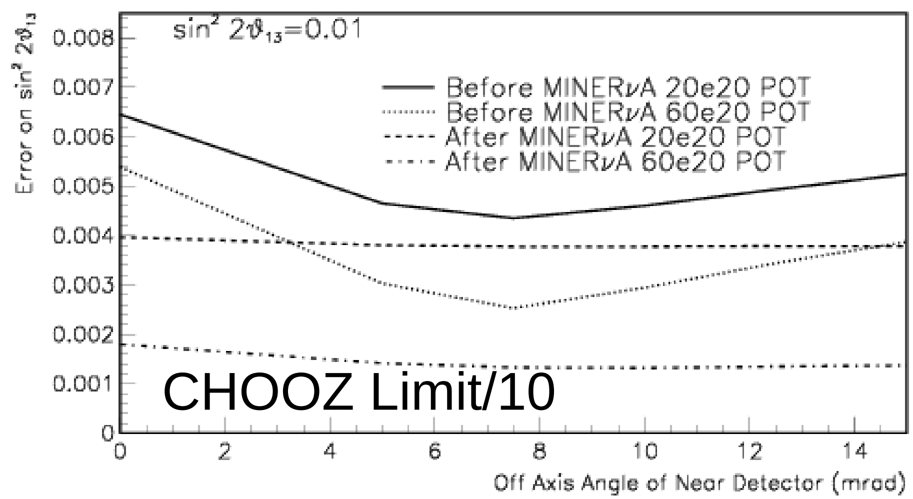


Statistical error, Phase I:15%

NOνA uncertainties, before and after precise cross section measurements

Process	QE	RES	COH	DIS
δσ/σ NOW (CC,NC)	20%	40%	100%	20%
δσ/σ after MINERνA (CC)	5%	5%	5%	5%
δσ/σ after MINERνA (NC)	n/a	10%	20%	5%





Before MINERνA, NOνA would be limited by cross section systematics (or be forced to have a different near detector)

NOνA Near Detector Thoughts

- NOνA needs to know cross sections for high or low values of Θ_{13}
  - Since $\sin^2 2\Theta_{23}$ is large, near and far event populations will be very different
  - if Θ_{13} is large, CC QE and RES cross sections important
  - if Θ_{13} is small, NC π^0 production cross sections important
- If Far Detector Backgrounds are really dominated by intrinsic ν_e events (TASD), then there's much more cancellation between near and far
- Need to consider for Δm^2 analysis: do we need to contain ν_μ CC events at the peak in ND? If so, need about 14m of near detector, not 10m!